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Form Approved
OMB No. 0704-0188

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1. REPORT DATE **01 SEP 2003**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Potential for Expansion of Coral Reefs into Higher Latitudes due to Climate Change**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Decision Systems Technologies, Inc. NOAA, E/RA31, SSMC1 1335 East-West Highway Silver Spring, MD 20910, USA**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002146. Oceans 2003 MTS/IEEE Conference, held in San Diego, California on September 22-26, 2003. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Potential for Expansion of Coral Reefs into Higher Latitudes due to Climate Change

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With the occurrence of recent strong climate events (e.g. El Niño 1997-1998 and La Niña 1999-2000) over the last couple of decades, it has become interesting to investigate if there have been any effects on Sea Surface Temperature (SST) at geographical margins of coral reefs.

It is generally accepted that the sea temperature range for coral reefs is 18-36°C, with the optimal range being between 22° and 28°C [1,2], although the limits of both high and low thermal stresses are species dependent and some corals in the Persian Gulf experience temperatures well outside of this range (11-36°C) and still survive. Coral reefs dominate coastal tropical environments between latitudes 25°S and 25°N, roughly coinciding with winter minimum water temperatures of 18°C and above. Some coral reefs reach to about 35°N in the Northern Hemisphere and 32°S in the Southern Hemisphere. All high latitude reefs are influenced by major warm currents flowing towards the poles, providing warm water, which replaces the cooler ambient temperatures, and a supply of new corals and other organisms. The Kuroshio Current off Japan carries corals as far north as about 34°N to Iki Island, Nagasaki Prefecture and Tateyama near Tokyo Bay at 35°N. These are the highest latitude coral reefs anywhere in the world. The Gulf Stream allows the Bermuda reefs to grow at about 32°N, which is the northernmost coral in the Atlantic Ocean; the Leewin Current warms the Houtman Abrolhos reefs off Western Australia close to 29°S, the southernmost in the Indian Ocean; and the East Australia Current permits reefs to grow around Lord Howe Island beyond 31°S, the most southerly coral reef in the world; the Brazil Current supports reefs in the Abrolhos Archipelago, Brazil near 18°S; and the Agulhas Current sustains high latitude coral reefs near St. Lucia, South Africa beyond 28°S. These warm currents are mostly western boundary currents.

In this study, the 9-km resolution satellite NOAA/NASA Ocean Pathfinder AVHRR global nighttime SST data were used to investigate the variation in geographic location of the annual minimum monthly mean 18°C SST isotherm from 1985 to 2001 in an attempt to understand the possible effects of recent climate change on the geographic extent of corals.

Two approaches were used for this investigation. In the first approach, 1985-2001 annual minimum monthly mean SST time series were constructed from the 9km satellite SST pixels at or next to selected high latitude coral reef sites that are listed in Table 1. These reef sites are within the areas influenced by major poleward warm currents. These time series were analyzed to investigate SST trends over the time period. Similar time series were also developed for other selected locations, listed in Table 2. The latter are under the influence of the same currents but at locations poleward of the Table 1 sites but where no reef-building corals have been observed. These time series are analyzed to investigate the existence of SST trends that may permit the settlement of new corals some time in the future.

In the second approach, 1985-2001 time series of the highest latitude reached by the annual minimum monthly mean SST of 18°C were constructed along each of seven selected coastlines or island chains (called transects hereinafter) in regions influenced by warm poleward flowing currents. These transects are listed in Table 3.

In both of the above approaches, the trends were calculated using linear regression analysis, for which the slope and standard error were calculated for each time series.

Table 1 presents the results from the regression analysis of the annual minimum monthly mean SST for selected high latitude reef sites. All of these sites, with the exception of St. Lucia on the southeast coast of Africa, have positive trends for the 1985-2001 time period. St. Lucia has a very weak decrease in SST over the same period, however the standard error is almost an order of magnitude greater than the slope.

Table 1
Regression analysis of the annual minimum monthly mean SST between 1985 and 2001 for the seven high latitude reef sites.

Reef site	Mean (°C)	Regression Slope (°C/yr)	Standard Error of Slope (°C/yr)
Bermuda	18.0	-0.020	0.163
Tateyama	15.0	0.033	0.040
Iki Island	13.9	0.045	0.032
Abrolhos Archipelago	23.8	0.042	0.026
St. Lucia	21.8	-0.003	0.022
Houtman Abrolhos	20.0	0.024	0.026
Lord Howe Island	18.6	0.028	0.028

Bermuda and Lord Howe Island have an average annual minimum monthly mean SST of close to 18°C, whereas both Japanese sites, Tateyama and Iki Land, have averages below 18°C. However, Abrolhos Archipelago (southeast coast of South America) and St. Lucia (southeast coast of Africa) have average annual minimum monthly mean SSTs well above 18°C. The higher average minimum SSTs of the last two sites may indicate that there are other factors such as substrate type, water quality, nutrient supply, etc. effecting settlement in these regions or suitable cool water coral species have not found their way into the areas via the ocean currents, as they have in the other regions.

The same analysis for other selected sites is presented in Table 2. With the exception of the southeast coast of North America, all trends are positive. These warming trends at the sites where minimum SSTs are around 18°C may allow corals to settle in these areas in the near future, provided that other factors are favorable for settlement. The annual minimum monthly mean SSTs at the site on the southeast coast of South America and at the site on the southeast coast of South Africa are well above 18°C, indicating that other factors may be preventing the settlement of coral in these areas.

Table 2
Regression analysis of the annual minimum monthly mean SST between 1985 and 2001 for the selected non-reef sites.

Site	Mean (°C)	Regression Slope (°C/yr)	Standard Error of Slope (°C/yr)
N. America SE* coast	18.4	-0.174	0.059
S. America SE coast	23.1	0.019	0.029
Africa SE coast	20.3	0.031	0.022
Rottnest Island	18.1	0.014	0.031
Australia SE coast	18.4	0.060	0.024

*SE: southeast.

Table 3 presents the regression analysis of the meridional movement of the 18°C isotherm for the annual minimum monthly mean SST along the selected transects.

Table 3
Regression analysis of the extent of the 18ºC isotherm for the annual minimum monthly mean SST between 1985 and 2001.

Site	Mean (°lat)	Regression Slope (°lat/yr)*	Standard Error of Slope (°lat/yr)
N. America SE** coast	34.96	0.011	0.032
Japan SE*** transect	33.42	0.035	0.038
Japan SW coast	31.59	0.026	0.015
S. America SE coast	-27.62	0.103	0.100
Africa SE coast	-33.96	0.008	0.011
Australia SW coast	-31.99	-0.009	0.040
Australia SE coast	-33.52	-0.115	0.052

* Positive value represents northward movement of the 18°C isotherm.
** SE: southeast; SW: southwest.
*** This is a transect in meridional direction running along an island chain in offshore direction off Tateyama between the north boundary of the Kuroshio Current and Japan mainisland.

From 1985 to 2001 the 18°C isotherm tended to migrate into higher latitudes on all Northern Hemisphere transects and along each side of Australia in the Southern Hemisphere. However, this is an average trend, and in all cases the 18°C isotherm migrated back and forth, often retreating back to or close to its original location. At a few cases it even retreated to lower latitudes than its original 1985 location (i.e. along the southeast coast of North America and southeast coast of Australia).

The poleward trends of the 18°C annual minimum monthly mean isotherms are more meaningful when consideration of recent strong climatic events such as the strong 1997-1998 El Niño are taken into account, since many of the observed inter-annual fluctuations can be

explained by the fact that these climatic events preferentially warm some regions and cool others.

In summary, preliminary results show that there is a positive trend in annual minimum monthly mean SST and a poleward movement of the 18°C isotherm at most of our selected locations. These tendencies imply that in some areas there is a potential for corals to expand into higher latitudes given that other factors such as substrate type, water quality, nutrient supply, etc. are suitable for settlement. New settlement can introduce coral into higher latitudes where water temperature was too cold for previous survival and increase biodiversity in existing high latitude coral reef systems.

Acknowledgements

The authors would like to thank Dr. James Hendee for his initial ideas and thank Ms. Chunying Liu for assistance in data processing.

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